Evaluation of Selected Insecticides Applied To High Moisture Sorghum Grain To Prevent Stored Grain Insect Attack

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ABSTRACT

Candidate insecticides were tested on high moisture sorghum as protectants against several species of stored-grain insects. The addition of 0.2 percent of propionic acid by weight to the high moisture sorghum to prevent spoilage did not influence insect infestations. The order of general effectiveness of the treatments at dosages applied was: pirimiphos-methyl > chlorpyrifos-methyl > fenitrothion > malathion > malathion-diatomaceous earth dust.

Key words: chlorpyrifos-methyl, diatomaceous earth, fenitrothion, grain protectants, high moisture grain, insecticide residues, Kenite 2-I, malathion, pirimiphos-methyl, repellency, sorghum protectants.

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife—if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

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SUMMARY

Candidate insecticides were tested as protectants on high moisture sorghum grain stored in small bins. Pirimiphos-methyl (*O*-[2-(diethylamino)-6-methyl-4-pyrimidinyl] *O,O*-dimethyl phosphorothioate) at 8.4 p/m, chlorpyrifos-methyl (*O,O*-dimethyl *O*-[3,5,6-trichloro-2-pyridyl] phosphorothioate) at 6.7 p/m, fenitrothion (*O,O*-dimethyl *O*-[4-nitro-*m*-tolyl] phosphorothioate) at 8.9 p/m, and malathion (diethyl mercaptosuccinate *S*-ester with *O,O*-dimethyl phosphorodithioate) at 16.7 p/m applied as water emulsions, and a malathion-diatomaceous earth dust at 11.2 p/m malathion were compared in tests with selected insects. The insects were rice weevils *Sitophilus oryzae* (L.), red flour bettles *Tribolium castaneum* (Herbst), confused flour beetles *T. confusum* Jacquelin duVal, flat grain beetles *Cryptolestes pusillus* (Schonherr), sawtoothed grain beetle *Oryzaephilus surinamensis* (L.), and lesser grain borers *Rhyzopertha dominica* (F.) during a 12-month storage study. The malathion emulsion spray was used as the standard treatment for comparison. Each treatment was replicated four times, and each replication consisted of 4 bu of grain stored in a 0.14 m^3 (5 ft^3) cylindrical fiberboard bin.

Damaging infestations of mixed populations of insects readily developed in all bins of the untreated check sorghum.

The moisture content of the grain decreased rather rapidly during the second and third months of storage; thereafter, a more or l stable level was maintained at room conditio of about 26.7° C and 60 percent relative h midity.

In the dust treatment, malathion residu degraded rapidly to about 0.5 p/m during t first month of storage; consequently, relative large infestations developed in all replicatio and considerable damage resulted. Malathi emulsion gave relatively good protection 1 6 months. After 12 months, a loss in te weight of 5.5 lb/bu (2.5 kg/25.5 kg) was corded. Losses of about 6.9 and 17.1 lb/bu (3 and 7.8 kg/25.5 kg) were found in grain fro bins with the dust treatment and the untreat checks, respectively.

Fenitrothion was effective in preventi damage to the grain during the 12 mont storage, but damaging infestations were esta lished in all replicates during the last month the test.

Chloropyrifos-methyl gave excellent prot tion for 12 months, and it was the most eff tive treatment against the lesser grain borer bioassays conducted at the termination of t study. At that time, about 26.7 percent of initial chloropyrifos-methyl deposit remained the sorghum.

Pirimiphos-methyl gave excellent protect against insect damage, test weight, and cal lated kernel weight losses. At the terminat of storage, an average of only 13.1 insects w found per 3,000-g sample in comparison to 5 and 242.8 in samples from the chlorpyrif methyl and fenitrothion treatments. About 4 percent of the initial pirimiphos-methyl resi remained on the sorghum after 12 months.

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BACKGROUND AND OBJECTIVES

Sorghum grain is harvested in late fall, and, under favorable weather conditions, it is often combined while the grain's moisture content is high. At other times, inclement weather prevents early maturity and harvest, and the moisture content of the grain remains high. High-moisture content is favorable for insect development and damage.

This report presents the findings of a small bin, intermediate-type study to determine the efficacy of selected dosages and formulations of malathion, fenitrothion, pirimiphos-methyl, and chlorpyrifos-methyl applied to high moisture grain sorghum.

MATERIALS AND METHODS

Previous to the treatments, the sorghum grain had been stored at a relatively low temperature in a concrete silo bin for about 6 weeks. Upon removal from the silo immediately before treatment, the sorghum grain was passed through a shaker and fan-type cleaner to remove most of the foreign material and to improve uniformity. After cleaning, the moisture content was 17.4 percent. If stored at this high moisture content, sorghum grain will become moldy and spoilage will result; consequently, propionic acid was applied at the rate of 0.2 percent by weight of the grain to prevent spoilage. The propionic acid was added immediately before the insecticides were applied to the grain.

The malathion-emulsion spray was prepared from premium-grade 57 percent malathion EC and distilled water. The emulsion, containing a dosage of 709.7 ml (1.5 pt) of the concentrate in 6.9 l (14.5 pt) of water, was applied by siphon movement through a Sprayings System Co. ¼-inch JN atomizing nozzle block at 1 kg/1.4 cm^2 (10 lb/in^2) air movement at the rate of 7.6 l (2 gal) of emulsion per 25.4 metric tons (1,000 bu) of grain. The block was fitted with No. 2050 fluid and No. 70 air nozzles to deliver a round spray pattern. The malathion spray treatment (16.7 p/m) was used as the standard chemical treatment for comparison with the other treatments.

A pirimiphos-methyl emulsion spray was prepared from a 0.6 kg/l (5 lb active ingredient (AI)/gal) emulsifiable concentrate (E.C.) (formulation YF6405) and distilled water for an 8.4 p/m treatment. The fenitrothion emulsion spray was prepared from a 0.96 kg/l (8 lb AI/gal) E.C. (formulation Accothion 8EC) and distilled water for an application rate of 8.9 p/m AI. Chlorpyrifos-methyl (formulation M-3721) emulsifiable concentrate containing 0.24 kg/l (2 lb AI/gal) was diluted with distilled water for a 6.7 p/m application.

The malathion-Kenite dust, hereafter designated as M+K dust, was prepared by mixing premium grade 57 percent malathion in Kenite 2–I (diatomaceous earth) dust at a rate of 0.47 l (1 pt) malathion to 27.2 kg (60 lb) dust for application to 25.4 metric tons (1,000 bu) (11.2 p/m malathion). The M+K dust applications were made 15 minutes after application of the propionic acid.

All the sprays were applied to 50.9-kg (2-bu) lots of sorghum in a steel barrel that rotated on its side at 16 r/m on an electric barrel roller. The insecticide was introduced through an aperture in the barrel lid while the barrel was turning. The grain was then thoroughly mixed by barrel rotation for an additional 10 minutes. Immediately after two lots were treated, the 4 bu of treated sorghum were placed in a 0.14 m^3 (5 ft^3) fiberboard barrel (drum).

The dust was added as 50.9 kg (2-bu) was poured into the steel mixing barrel. The barrel was rotated for 15 minutes for the dust treatments. After treatment the grain was placed in the drums, and the surface of the grain was immediately leveled to provide equal exposure areas in all bins. Each bin represented a treatment replicate, and all treatments were replicated four times with four (untreated sorghum) check bins. The check bins were also treated with propionic acid.

The bins were stored in a 5.2- by 6.7-meter (17- by 22-ft) room equipped with constant temperature and relative humidity (RH) controls to maintain the temperature at 26 $\pm$ 1.1° C and 60 $\pm$ 5 percent RH. A photoelectric control provided 12-hour dark and light periods. Treatments were placed in bins in a

selective, randomized arrangement to uniformly distribute each treatment in four widely separated areas of the storage room.

Major insect releases each of about 6,000 rice weevils *Sitophilus oryzae* (L.), 3,000 red flour beetles *Tribolium castaneum* (Herbst), 3,000 confused flour beetles *T. confusum* Jacquelin duVal and lesser numbers of flat grain beetles *Cryptolestes* spp., and sawtoothed grain beetles *Oryzaephilus surinamensis* (L.) were made in the storage room 14, 35, 70, 110, 135, 150, 190, and 235 days after the experiment was started. These insects were scattered in the aisles and around the bins. Jar cultures of flat grain beetles *C. pusillus* (Schonherr), and sawtoothed grain beetles *O. surinamensis* (L.) were maintained in the storage room from the third month until the test was terminated.

RESULTS

The rates of application will not be shown in the tables as there was only one dosage of each formulation. The rates were as follows: malathion (emulsion) 16.7 p/m, pirimiphos-methyl 8.4 p/m, chlorpyrifos-methyl 6.7 p/m, fenitrothion 8.9 p/m and malathion in the M+K dust 11.2 p/m.

Laboratory evaluations (both efficacy and chemical analyses) of the effect of the propionic acid, which were conducted as a separate study, clearly indicated that the addition of the propionic acid to the grain before insecticide application did not materially affect the efficacy and degradation of the residues.

Grain Temperature and Moisture

Slight elevations in grain temperatures were first noted in bins of untreated sorghum and sorghum treated with the M+K dust treatment during the last week of the second month of storage (table 1). Insect activity caused the temperatures to rise rapidly in the untreated and the M+K dust treated grain bins during the third month. No appreciable temperature elevations from insect activity occurred in bins of sorghum treated with pirimiphos-methyl and chlorpyrifos-methyl during the 12 months' storage. Elevations occurred in sorghum treated with malathion emulsion beginning the latter part of the 8th month and in sorghum treated with fenitrothion during the 12th month.

Sorghum in the untreated checks contained about 17.4 percent moisture when the experiment was started, but during the second and third month, the moisture level had fallen to about 13 percent. During the last 6 months of storage, the moisture of the sorghum with the most effective treatments remained about 12 percent (table 2).

SAMPLING

For detailed studies, samples were taken from each bin with a nonpartitioned grain trier after 1, 3, 6, 9, and 12 months' storage. The probe was inserted vertically near the center and about 6 cm from the bin wall in each of the four quadrants until about 3,000 g were

TABLE 1.—*Average sorghum grain mass temperatures (°C) during 12 months' storage*[1]

Insecticide	Months of storage											
	1	2	3	4	5	6	7	8	9	10	11	12
Sprays:												
Malathion	25.7	25.9	25.6	26.0	27.4	27.1	26.6	27.4	28.7	29.9	30.1	30.8
Pirimiphos-methyl	26.1	26.0	25.8	26.0	27.7	27.1	26.4	26.7	26.8	26.4	26.3	26.7
Fenitrothion	25.9	26.4	25.8	26.1	27.6	27.3	26.6	26.7	26.7	26.4	26.3	28.1
Chlorpyrifos-methyl	25.7	25.8	25.6	25.9	27.5	27.3	26.2	26.6	26.6	26.4	26.4	26.8
Dusts:												
M+K	26.0	26.6	27.8	31.4	31.3	29.8	27.9	28.2	28.1	27.9	27.7	27.9
Untreated:												
Check	26.3	26.6	29.7	34.2	35.1	36.6	35.3	35.0	34.6	33.1	31.1	31.1

[1]Propionic acid applied at the rate of 0.2 percent by weight of grain to prevent spoilage.

TABLE 2.—*Average (percentage) moisture content of sorghum grain at given intervals after insecticide treatment*[1]

Insecticide	Months of storage 1	3	6	9	12
Sprays:					
Malathion	17.2	13.1	12.1	12.6	12.0
Pirimiphos-methyl	17.0	13.1	12.1	12.2	12.0
Fenitrothion	16.9	13.4	12.2	12.3	12.0
Chlorpyrifos-methyl	16.9	12.9	11.9	12.3	12.0
Dusts:					
M+K	17.5	13.6	12.5	12.7	12.3
Untreated:					
Check	16.8	13.4	12.5	13.3	12.8

[1]Propionic acid applied at the rate of 0.2 percent by weight of grain to prevent spoilage.

taken from each bin. Probings were also made for residue samples and other studies as required.

All subsamples used in the toxicity, food preference, and repellency studies were held in a deep freeze at −20° C for 7 days to eliminate all self-contained insect infestations that might be present. Before testing, these samples were held at 26° and 60 percent RH for 48 h to allow for temperature and moisture equation.

Replicated 200-g subsamples were placed in 1-pt screen-covered mason jars for the bioassay toxicity tests. Groups of about 50 adult insects —rice weevils, red flour beetles, confused flour beetles, and lesser grain borers—were placed in separate jars. Mortality counts were made 21 days later, and the live and dead insects were discarded. All fine dusts removed from the samples during the screenings made for the mortality counts were returned to the respective jars. The subsamples were then held for the emergence of F_1 progeny, and all subsamples were retained for an additional time for a visual assessment of damage by developing infestations, if any were established.

For tests of the acceptance or avoidance of the wheat treated with the different formulations, about 250 rice weevils were released in the depressed center of multi-choice food selection or food preference chambers. In each of the chambers, six 237 ml (½-pt) cardboard cartons, each filled with sorghum from one of the five different insecticide treatments and from the untreated check, were exposed to the dispersal of the rice weevils. The weevils were allowed 24 hours to enter, move, or remain in the cartons of grain. The weevils were then sifted from the grain for counting. These tests were conducted 1, 3, 6, and 9 months after treatment.

Repellency tests were conducted with replicated samples from all bins 1, 3, and 6 months after treatment. The treated grain was compared with untreated, uninfested source grain. Five 237 ml (½-pt) cartons of treated grain from a bin and five of untreated grain were alternated in the apparatus. About 500 rice weevil adults (14 days old) were liberated in the depressed release area located in the center of the chamber to scatter over the dispersal plane. The weevils were given 24 hours to choose from among the cartons of treated and untreated grain. Following the dispersal period, the weevils were sifted from the grain and counted.

The grain temperature in all bins was taken weekly by inserting a glass thermometer into the center of the grain mass. Samples for residue analysis were taken with the nonpartitioned grain trier.

When the storage was terminated, additional 3,000-g samples were probed from each bin. These samples were passed over a 10-mesh screen to remove the insects, kernel bits, dusts, and frass. The screenings were sifted over a No. 20 sieve to separate the insect frass and other dusts from the insects and kernel bits. The frass and dusts were weighed to estimate the insect damage to the grain; this material was remixed with the sifted grain and was stored in covered 1-gal glass jars. Then these samples were held for 63 days to observe insect development and to make a final count of progeny. The samples were then held for an additional period to assess the amount of progeny damage.

Samples of 1,000 kernels from each of the bins were examined after 3, 6, 9, and 12 months' storage to determine the percent of the kernels showing insect feeding and damage. The weight loss caused by the damage on the kernels was determined from these samples.

Residues

The results of the residue analyses are shown in table 3. The samples of wheat treated with the M+K dust indicated that practically all of the malathion disappeared during the first

TABLE 3.—*Average residues in parts per million (p/m) on sorghum grain stored in small bins*[1]

Insecticide	Intended dosage	Day 1	Months of storage: 1	2	3	4	5	6	8	9	12
Sprays:											
Malathion	16.7	13.4	3.8	2.6	1.6	1.7	1.4	1.5	1.2	0.9	0.8
Pirimiphos-methyl	8.4	7.5	6.5	4.7	4.3	4.2	4.4	3.8	4.1	3.8	3.7
Fenitrothion	8.9	6.1	4.0	3.4	3.0	2.2	2.5	2.0	1.5	1.3	1.1
Chlorpyrifos-methyl	6.7	6.0	5.0	4.1	3.5	3.3	2.7	2.6	2.2	1.9	1.6
Dusts:											
Malathion	11.2	9.1	.5	.5	.3	.2	.3	.2	.2	.2	.1

[1]Propionic acid applied at the rate of 0.2 percent by weight of grain to prevent spoilage.

month of storage. Malathion applied as an emulsion also degraded rapidly; however, sufficient residues remained to give considerable protection during the first 6-months' storage. After 12 months' storage, nearly 50 percent of the initial deposit of pirimiphos-methyl, and about 27 and 18 percent of the chlorpyrifos-methyl and fenitrothion, respectively, remained on the sorghum grain. These active residues greatly influenced the efficacy of these materials throughout storage.

Insect Populations

The numbers of live adult insects recovered from the 3,000-g probe samples taken after 3, 6, 9, and 12 months' storage indicated the active populations within the bins (table 4). After 3 months' storage, an average of 1,745.1 live insects were found in the samples from the untreated sorghum; after 6 months, 1,447.8; after 9 months, 1,431.9; and after 12 months, 740.6. The malathion emulsion began losing its effectiveness during the latter 6 months of storage as 739.8 and 822.8 live insects were recovered from the 9- and 12-month samples, respectively. After 12 months' storage, an average of 242.8, 55.3, and 13.1 live insects were recovered from fenitrothion, chlorpyrifos-methyl, and pirimiphos-methyl samples, respectively. Large numbers of dead insects were found in all samples of insecticide-treated sorghum.

Food Selection Studies

Competitive multichoice offerings from the different bins to 14-day-old rice weevil adults showed that only the M+K dust treatment affected the acceptability of the sorghum grain; however, grain with this treatment was accepted more readily as the storage period was prolonged (table 5). From 97.3 to 100 percent of the weevils released in the chambers entered the test cartons.

Repellency Studies

Repellency studies, which were conducted with five replicated samples from each bin 1, 3, and 6 months after treatment, were compared

TABLE 4.—*Average number of live adult insects recovered from 3,000-g samples of sorghum grain during 12 months' storage*

Insecticide	3 months: Rice weevils	*Tribolium* spp.	Other	6 months: Rice weevils	*Tribolium* spp.	Other	9 months: Rice weevils	*Tribolium* spp.	Other	12 months: Rice weevils	*Tribolium* spp.	Other
Sprays:												
Malathion	26.5	3.0	0.8	28.3	17.5	57.8	680.0	37.0	22.8	644.0	140.8	38.0
Pirimiphos-methyl	12.8	0	.5	1.0	1.8	24.8	20.3	34.3	.8	6.5	3.8	2.8
Fenitrothion	16.6	4.8	2.3	1.3	12.3	36.0	157.0	11.0	0	198.3	34.5	10.0
Chlorpyrifos-methyl	8.3	2.3	.8	0	3.5	19.5	27.3	11.0	2.0	36.5	16.0	2.8
Dusts:												
M+K	1.8	0	0	436.0	75.0	60.8	313.3	67.8	49.8	92.3	41.8	20.5
Untreated:												
Check	1,521.3	76.5	147.3	451.0	583.0	413.8	688.3	661.8	81.8	227.3	504.8	8.8

TABLE 5.—*Percentage of rice weevils that entered samples of sorghum grain in food selection*[1]

Insecticide	Months of storage 1	3	6	9
Sprays:				
Malathion	18.2	17.3	16.1	17.1
Pirimiphos-methyl	19.8	16.1	17.3	18.3
Fenitrothion	19.3	17.4	18.4	15.1
Chlorpyrifos-methyl	18.6	18.2	17.0	17.1
Dust:				
M+K	8.4	11.8	14.1	15.1
Untreated:				
Check	15.7	19.2	17.2	17.3

[1]Averages of 8 replicated offerings.

with the cleaned, untreated grain sorghum retained from the source lots used for all treatments. None of the spray treatments were repellent (table 6). The M+K dust caused the sorghum grain to be repellent but not to the high degree previously found in the sorghum of moisture contents of 12.5 percent or lower when treated. Repellency that the M+K dust imparted initially, gradually lessened as the storage period was extended. From 94.2 to 98.6 percent of the weevils released in the chambers entered the test cartons.

TABLE 6.—*Percentages of repellency and preference shown by adult rice weevils to sorghum grain*

Insecticide	Repellency after interval of— 1 month: Repellency[1]	Preference shown[2]	3 months: Repellency[1]	Preference shown[2]	6 months: Repellency[1]	Preference shown[2]
Sprays:						
Malathion	−1.61	50.81	2.01	49.00	−2.01	51.00
Pirimiphos-methyl	−1.20	50.60	−.80	50.20	2.01	49.00
Fenitrothion	1.59	49.20	5.22	47.39	−5.22	52.61
Chlorpyrifos-methyl	12.00	44.00	−.60	50.20	−3.62	51.81
Dust:						
M+K	33.60	33.20	23.39	38.31	12.00	44.00
Untreated:						
Check	.40	49.80	−4.00	52.00	−8.43	54.22

[1]Equation for repellency: $100-(T\div\frac{U+T}{2}\times 100)$ where U is the number of insects in the untreated grain and T, the number in the treated grain (0 = no repellency).

[2]Equation for preference shown: $\frac{T}{T+U}\times 100$ (50 = no preference shown).

TABLE 7.—*Weight of insect frass per 3,000-g sample of insecticide-treated grain sorghum after 12 months' storage*

Insecticide	Average[1]	Range
	Grams	*Grams*
Sprays:		
Malathion	89.8	62.6-122.4
Pirimiphos-methyl	12.2	8.3- 18.2
Fenitrothion	21.8	16.6- 30.4
Chlorpyrifos-methyl	15.8	9.1- 23.2
Dust:		
M+K	140.5	101.4-190.2
Untreated:		
Check	185.6	140.6-239.0

[1]Four replications.

Insect Damage

Assessments of insect damage to the sorghum grain recorded after 12 months' storage included the amounts of insect frass in samples, losses in test weight, percentages of kernels damaged by insects, and kernel weight losses. Weights of fine dusts, primarily insect frass, sifted from 3,000-g samples taken by probing at the end of the storage period, indicated the damage from insect feeding during storage (table 7).

The small amounts of dusts recovered from the bins with the pirimiphos-methyl and chlorpyrifos-methyl treatments suggested a relatively small amount of insect damage to the sorghum grain. The slightly larger amounts of dusts which were recovered from the fenitrothion-treated sorghum also indicated little damage when compared to the damage in sorghum from the malathion treatment and the untreated sorghum. Heavy damage was inflicted in the M+K dust treatment.

Damage in terms of weight loss caused by insect feeding is important in evaluating the effectiveness of a protectant material. The changes in the test weight of the grain sorghum are shown in table 8. The application of the M+K dust initially reduced the test weight of the sorghum by about 2.2 lb/bu. The dust adheres to the kernels and affects flowability, settling, and nestling qualities; consequently, fewer kernels are found in a given volume. This measurable loss lowers the grade of the sorghum grain.

Small weight losses, less than 1.4, 1.9, and 3.4 percent, were recorded in sorghum treated

TABLE 8.—*Average test weights per bushel (pounds) of samples of insecticide-treated sorghum grain at given intervals during 12 months' storage*[1]

Insecticide	Immediately after treatment	Months of storage 3	6	9	12	Lost during storage
Sprays:						
Malathion	59.10	58.70	58.50	56.90	53.60	5.50
Pirimiphos-methyl	59.05	59.05	59.00	58.85	58.20	.85
Fenitrothion	59.10	59.00	58.90	58.75	57.20	2.00
Chlorpyrifos-methyl	59.10	59.05	59.05	58.85	58.00	1.10
Dust:						
M+K[2]	56.90	55.25	54.80	53.65	50.05	6.85
Untreated:						
Check	59.05	56.60	54.45	45.60	42.00	17.10

[1]Average initial test weight of 4 samples from each lot before treatment was 59.10 lb/bu.

[2]The initial loss of 2.2 lb during treatment was caused by the addition of the diatomaceous earth.

with pirimiphos-methyl, chlorpyrifos-methyl, and fenitrothion. These losses are the direct result of many insects feeding on the grain before they were killed and not losses caused by the establishment of indigenous infestations during the 12 months' storage. Losses of about 9.3 and 12.0 percent by weight, were found in sorghum treated with malathion emulsion spray and the M+K dust, respectively. A loss of about 28.9 percent of the weight occurred in the untreated sorghum.

The calculated kernel weight losses caused by the feeding of insects throughout the 12 months' storage period are shown in table 9.

TABLE 9.—*Percentage of kernel damage and calculated kernel weight loss in samples of insecticide-treated sorghum grain during 12 months' storage*[1]

Insecticide	Kernels damaged in samples after— 3 mos.	6 mos.	9 mos.	12 mos.	Weight loss[2]
Sprays:					
Malathion	0.35	3.06	9.42	17.23	6.26
Pirimiphos-methyl	.20	1.16	1.50	2.15	.41
Fenitrothion	.39	1.54	4.75	6.50	1.65
Chlorpyrifos-methyl	.20	1.01	1.76	2.20	.58
Dust:					
M+K	2.75	5.05	16.30	25.50	11.87
Untreated:					
Check	10.05	23.76	52.25	70.10	27.77

[1]Average of 4 replications per treatment.

[2]Weight of undamaged whole kernels average 0.0217 g.

Kernels that are damaged by extensive internal feeding are often broken up during sampling and handling procedures, and, consequently, are not recorded by this method of determining the amount of kernel damage.

Insect damage was extensive in the untreated checks; in comparison, damage was light in sorghum from the pirimiphos-methyl and chlorpyrifos-methyl treatments. The sorghum with the M+K dust treatment was heavily damaged.

Toxicity Studies

In studies conducted 24 hours after the insecticide application, adult rice weevils were killed by all insecticide treatments, and the few progeny which emerged from the grain sorghum treated with the malathion emulsion spray and the M+K dust treatments were killed before establishing indigenous infestations. Table 10 summarizes the results of all exposures made 3, 6, 9, and 12 months after treatment. Excellent kills of adult rice weevils were recorded in samples from the pirimiphos-methyl and chlorpyrifos-methyl treatments. Fenitrothion gave excellent kills of adult rice weevils for 9 months but F_1 progeny damage occurred at that time. Malathion emulsion gave high mortality of adults in the 6-month exposures and suppressed the numbers of F_1 progeny for 12 months. The M+K dust was not effective in any of the exposures.

Pirimiphos-methyl gave good control of the confused flour beetle adults for 6 months, and only a few progeny were produced during the last 6 months of storage. None of the other treatments were effective in killing the adults; however, chlorpyrifos-methyl prevented F_1 progeny production.

Pirimiphos-methyl was effective against red flour beetles. Chlorpyrifos-methyl was effective against the adults for 6 months and prevented progeny production for the entire 12-months' storage. The other treatments were relatively ineffective against the adults, but fenitrothion suppressed progeny production for the entire storage period.

Chlorpyrifos-methyl was the most effective treatment against the lesser grain borers; considerable damage to the sorghum was inflicted by this species in all other treatments.

Table [illegible].—Average percentage insect mortality after 21 days' exposure insecticide-treated sorghum grain and subsequent number of the F_1 progeny emerging after infestation

	Insects exposed for 21 days in grain sorghum samples taken after a storage period of—											
	3 months			6 months			9 months			12 months		
	Mortality	Progeny		Mortality	Progeny		Mortality	Progeny		Mortality	Progeny	
		Total	Dead		Total	Dead		Total	Dead		Total	Dead
	Percent	*Number*	*Percent*	*Percent*	*Number*	*Percent*	*Percent*	*Number*	*Percent*	*Percent*	*Number*	*Percent*
RICE WEEVIL ADULTS—PROGENY COUNTED 63 DAYS AFTER INFESTATION												
Sprays:												
Malathion	100.0	184.0	97.6	90.5	42.4	25.0	44.2	66.2	2.0	12.1	69.2	1.0
Pirimiphos-methyl	100.0	15.5	100.0	100.0	14.5	100.0	100.0	20.5	100.0	100.0	30.3	100.0
Fenitrothion	100.0	27.3	96.3	100.0	85.0	97.6	95.4	315.0	48.6	13.5	711.0	2.3
Chlorpyrifos-methyl	100.0	10.8	100.0	100.0	23.0	100.0	100.0	65.0	100.0	100.0	131.0	85.7
Dust:												
M+K	60.9	291.0	16.0	76.1	248.3	35.8	46.4	259.5	25.3	39.7	234.8	1.9
Untreated:												
Check	1.8	1203.3	.7	0	1018.1	1.1	0	574.0	0	0	702.0	0
CONFUSED FLOUR BEETLE ADULTS—PROGENY COUNTED 77 DAYS AFTER INFESTATION												
Sprays:												
Malathion	5.2	25.0	4.0	7.5	20.0	25.0	0.1	23.0	0	0	41.0	0
Pirimiphos-methyl	94.2	1.5	100.0	83.4	2.0	100.0	51.9	1.5	66.7	15.9	2.8	27.3
Fenitrothion	1.0	24.0	50.0	2.0	20.0	50.0	0	14.0	0	0	30.0	0
Chlorpyrifos-methyl	9.5	0	—	9.6	0	—	4.6	0	—	4.2	2.0	50.0
Dust:												
M+K	0.5	41.0	0	1.0	74.8	.7	.5	46.8	0	0	64.3	0
Untreated:												
Check	0	105.2	0	0	116.2	0	0	77.6	0	0	98.2	0
RED FLOUR BEETLE ADULTS—PROGENY COUNTED 70 DAYS AFTER INFESTATION												
Sprays:												
Malathion	22.0	0	—	9.2	8.0	37.5	2.3	24.0	0	3.3	36.0	0
Pirimiphos-methyl	100.0	0	—	100.0	0	—	100.0	4.0	100.0	75.4	1.5	100.0
Fenitrothion	87.5	0	—	16.7	0	—	9.8	2.0	50.0	0	4.0	25.0
Chlorpyrifos-methyl	100.0	0	—	97.3	0	—	42.0	0	—	18.4	0	—
Dust:												
M+K	32.7	35.0	17.1	13.3	62.0	8.1	1.8	85.3	2.9	5.5	69.0	9.4
Untreated:												
Check	3.7	56.0	0	2.3	80.0	0	1.0	88.0	0	0	67.8	0
LESSER GRAIN BORER ADULTS—PROGENY COUNTED 70 DAYS AFTER INFESTATION												
Sprays:												
Malathion	20.3	88.0	1.1	5.7	235.0	0	3.2	333.3	1.5	6.2	622.0	0
Pirimiphos-methyl	34.6	36.0	22.0	32.3	21.3	1.2	36.3	25.5	2.9	5.7	83.0	0
Fenitrothion	14.6	54.0	11.1	12.0	80.0	.9	8.0	159.0	0	1.4	224.8	0
Chlorpyrifos-methyl	82.7	4.0	25.0	38.7	7.0	42.9	43.7	5.3	19.0	3.0	7.0	14.3
Dust:												
M+K	35.6	97.0	2.2	2.0	1,116.0	.2	13.3	1,206.0	.2	12.7	682.3	.5
Untreated:												
Check	0	108.3	.4	.5	1,060.0	1.1	0	724.0	0	.5	1,251.3	.1

TABLE 11.—*Visible damage by the insect progeny in samples of insecticide-treated sorghum grain after toxicity tests*

Insecticide	Damage observed 120 days after infestation of samples taken after storage of—[1]			
	3 mos.	6 mos.	9 mos.	12 mos.
	Rating	*Rating*	*Rating*	*Rating*
	RICE WEEVIL PROGENY			
Sprays:				
Malathion	0.8	4.5	4.5	5.0
Pirimiphos-methyl	0	0	0	0
Fenitrothion	0	0	2.0	4.5
Chlorpyrifos-methyl	0	0	.8	1.3
Dust:				
M+K	4.8	4.3	4.8	[2]5.0
Untreated:				
Check	[2]5.0	[2]5.0	[2]5.0	[2]5.0
	CONFUSED FLOUR BEETLE PROGENY			
Sprays:				
Malathion	0	0	1.8	3.0
Pirimiphos-methyl	0	0	0	0
Fenitrothion	0	0	1.0	2.5
Chlorpyrifos-methyl	0	0	0	0
Dust:				
M+K	2.3	2.0	2.3	2.3
Untreated:				
Check	2.5	2.5	2.3	3.0
	RED FLOUR BEETLE PROGENY			
Sprays:				
Malathion	0	0	1.8	2.5
Pirimiphos-methyl	0	0	0	0
Fenitrothion	0	0	1.0	2.0
Chlorpyrifos-methyl	0	0	0	0
Dust:				
M+K	2.0	1.5	2.5	3.0
Untreated:				
Check	2.8	2.5	2.5	3.0
	LESSER GRAIN BORER PROGENY			
Sprays:				
Malathion	1.5	4.0	4.5	5.0
Pirimiphos-methyl	1.0	1.5	2.0	4.0
Fenitrothion	1.5	3.0	3.5	4.5
Chlorpyrifos-methyl	0	.5	1.0	1.5
Dust:				
M+K	5.0	5.0	[2]5.0	[2]5.0
Untreated:				
Check	5.0	5.0	[2]5.0	[2]5.0

[1]Damage rating code: 0 = no visible infestation; 1 = slight damage as evidenced by a few insects and a small amount of insect frass; 2, 3, and 4 = ascending numbers of insects and corresponding amounts of insect frass; 5 = large infestation with great amounts of insect frass and spoilage of grain.

[2]Reading 90 days after infestation.

Damage Caused by Progeny

Estimates of the extent of damage caused by the establishment of infestations by the progeny of the adult insects introduced in toxicity (bioassay) tests when the samples were held for 120 days following infestation are shown in table 11. The pirimiphos-methyl was effective in preventing the establishment of rice weevil infestations, and chlorpyrifos-methyl greatly suppressed damage by this insect.

Infestations by confused flour beetles and red flour beetles were prevented by the pirimiphos-methyl and chlorpyrifos-methyl treatments. Chlorpyrifos-methyl did not effect high mortality in the toxicity tests with the confused flour beetle, table 10, but progeny development was suppressed and damage was prevented. Malathion and fenitrothion prevented progeny damage for 6 months.

Damage to sorghum samples retained from the toxicity tests indicated that lesser grain borers were the most difficult to control of any of the test insects used and inadequate control of the adults was generally obtained in the toxicity tests (table 10). Only chlorpyrifos-methyl greatly suppressed progeny production, but even then, progressive damage was inflicted on the sorghum according to the length of the storage period.

Insect Emergence

The extent of the infestations that had been established in the bins of sorghum grain after

TABLE 12.—*Average number of live adult insects emerging from 3,000-gram samples of insecticide-treated sorghum grain after 12 months' storage*[1 2]

Insecticide	Rice weevils	*Tribolium* spp.	Grain beetles[3]	Other	Total
Sprays:					
Malathion	1,467.5	237.0	391.5	46.8	2,142.8
Pirimiphos-methyl	30.3	21.5	18.2	6.0	76.0
Fenitrothion	731.4	76.3	290.0	21.2	1,118.9
Chlorpyrifos-methyl	37.0	92.8	21.3	7.0	158.1
Dust:					
M+K	1,296.5	303.5	417.3	62.0	2,079.3
Untreated:					
Check	702.0	247.0	503.8	40.3	1,492.1

[1]Samples held for 65 days for emergence of insects.
[2]Average of 4 replications per treatment.
[3]*Cryptolestes* and *Oryzaephilus* spp.

12 months' storage is shown by the emergence of insects from the 3,000-g samples probed from each bin when the test was terminated (table 12). All bins were infested. The least number of insects emerged from samples with the pirimiphos-methyl treatment, but only slightly larger numbers emerged from sorghum treated with chlorpyrifos-methyl. All other sorghum was heavily infested at the end of 12 months' storage.

CONCLUSIONS

The protectant properties of three candidate emulsifiable concentrates and one dust were compared with those of the standard malathion treatment. The results were consistent within the replications of each treatment throughout the storage study. A high correlation was found between the results of the different methods of evaluation of effectiveness of the individual treatments.

The following conclusions were made:

1. The application of 0.2 percent by weight of propionic acid to the sorghum grain did not affect the acceptability of the sorghum grain by the insects nor adversely influence insect infestations.
2. Residues resulting from the application of the malathion emulsion degraded rapidly from the initial deposit of 13.4 to 3.8 p/m during the first month of storage, but thereafter a gradual reduction occurred.
3. The residues resulting from the malathion dust application degraded from the initial deposit of 9.1 to 0.5 p/m during the first month of storage.
4. Initial residue deposits of 89.3, 89.6, and 68.5 percent of the intended dosages were obtained for pirimiphos-methyl, chlorpyrifos-methyl, and fenitrothion, respectively.
5. The application of the M+K dust reduced the test weight of the sorghum about 2.2 lb per bushel.
6. Treatment with pirimiphos-methyl prevented the establishment of insect infestations in the bins during 12 months' storage, and prevented appreciable losses in test weight and damage to the kernels.
7. About 49.3 percent of the initial deposit of pirimiphos-methyl remained in the sorghum after 12 months' storage.
8. Chlorpyrifos-methyl residues degraded gradually during the 12-month storage. After 12 months' storage, 26.7 percent of the initial deposit remained on the sorghum.
9. Treatment with chlorpyrifos-methyl prevented the establishment of damaging insect infestations in the bins of sorghum during 12 months' storage, and prevented appreciable losses in test weight and damage to the kernels.
10. Fenitrothion residues degraded gradually, but only about 18 percent of the initial deposit remained after 12 months' storage.
11. Fenitrothion was more effective than malathion, but large indigenous infestations did become established in all bins during the last part of the storage period.
12. The M+K dust treatment imparted repellency initially; however, most of the repellent action was lost during the first 6 months of storage.
13. The order of general effectiveness of the treatments at the dosages applied to the high-moisture sorghum grain was: pirimiphos-methyl > chlorpyrifos-methyl > fenitrothion > malathion > M+K dust.